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South American Volcanoes and Great Earthquakes

Volcano-Seismic Correlation vs. Secular PM

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Extended Abstract

Introduction. Astronomy was influential on the affirmation of mobilism in Earth science. It is sufficient to recall that in Observatories frequently in the past took place combined duties of astronomy, meteorology, geomagnetism, seismology. The ideas circulated among insiders not as specialized as today: the work of Schiaparelli (14 March 1835 - 4 July 1910) was ranging from mathematics to astronomy, geophysics and the history of science, the latter built on deep knowledge of ancient linguistics (Celoria, 1910; Gabba, 1947). At least four were the Schiaparelli's conjectures (Schiaparelli, 1883, 1891; Gribaudi, 1902) on the causes and consequences of the motion of the pole.

Modern geodynamical conjectures and data. In an asymmetrically expanding Earth framework (Hilgenberg, 1974; Carey, 1976; Owen, 1976; Scalera, 2003, 2006, 2010a; among many others) we have to expect a region where the litospheric tissue more intensely undergone the process envisaged by Schiaparelli, were a communication between deep interior and surface of the planet is established. Because the maps of the expansion rates of the oceans (Larson et al., 1985; McElhinny and McFadden, 2000) show a maximum expansion rate on the Nazca region, we should expect that eventual peculiar phenomena related to this planetary expanding side would be observable on the Pacific margin of South America.

During his trip on the Beagle, Charles Darwin (1840) wrote about the eruptions associated to the Conception earthquake of 1835. Lorenzo Casertano's survey (1962) following the 1960 great Chilean earthquake found some unclear evidence of a link between eruptions and the seismic event. Scalera (2008) using the data available in 2006 in the Smithsonian Institution Catalog of volcanic eruptions revealed grounded evidence that South-American Wadati-Benioff zone earthquakes with magnitude greater than 8.4 are associated to an enhanced rate of volcanic eruptions, but still it was impossible to determine the causal chain between the two phenomena. An average return period of about 45 years was deducible from the data for the time window 1800-2010. After 2006, the Smithsonian Institution has greatly increased the completeness of the catalog (Siebert et al., 2011) adding the new eruptions for the 2000-2010 interval, but also adding a 60% of new entries in the list of the Andean volcanoes. The occurrence of

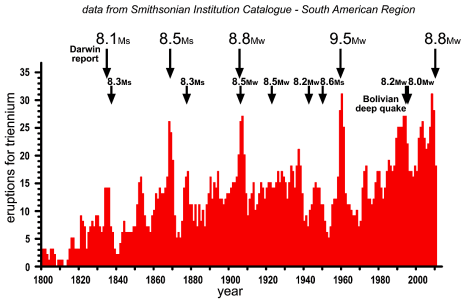

Fig. 1. Using the complete Smithsonian catalog of eruption data of the Andean belt from 1800 to 2010, the triennial number of eruptions along the time axis has been plotted. All the non-discredited data have been used. Cusps of eruptions coinciding with the occurrence of great-magnitude earthquakes are confirmed, and an additional peak is correlated to the 2010 Maule quake (M=8.8). At the moment no explanation exists for all the large fluctuations and marked minima in the eruption rate. But it must be stressed that a number of strong seismic events exist that does not correlate with peaks of the triennial rate of eruption, leading to the conclusion that different processes can cause strong earthquakes, but only a sub-set of them can cause the volcano-seismic events. In 1994, the occurrence of very deep and strong seismic event in Bolivia (M=8.2; depth=641 km, data USGS, 2007) is preceded by a decennium of increased rate of eruptions.

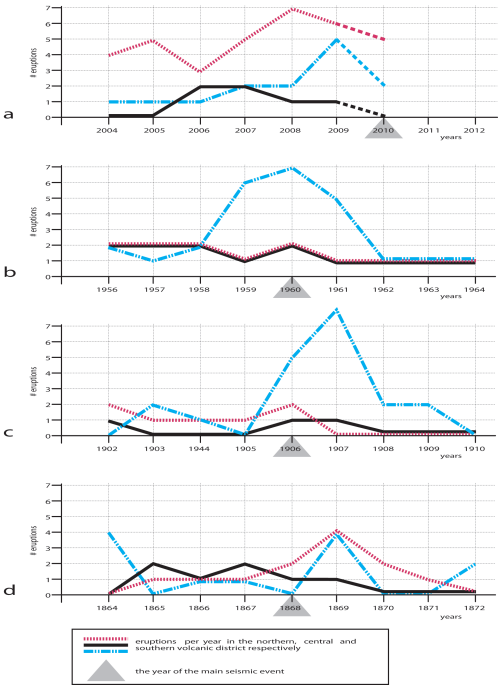

Fig. 2. Rate of eruptions for year on the three volcanic districts of the Andean Pacific margin for the events of a) 2010, b) 1960, c) 1906 and d) 1868. Passing from the oldest volcano-seismic correlation event of 1868 to the recent one of 2010, the maxima migrate from a position on the time axis following the earthquake to a position preceding the seismic event. This can be caused by uncertain information about the date of onset of the eruptions in historical times. The precursory increasing rate of eruption must be confirmed with future occurrence of correlation events.

the Chilean Maule earthquake of 27 February 2010 (M=8.8) – occurred at five decades from the 1960 one – has been the occasion to rework all the data in searching for additional clues able to indicate a preferred causal direction eruptions-earthquakes or earthquakes-eruptions or from a third more general cause (e.g. a mantle movements) to both eruptions and earthquakes.

A series of papers deal with the triggering of eruptions by earthquakes at different distances from the hypocentral region (Uffen and Jessop, 1963; Latter, 1971; Carr, 1977; Barrientos, 1994; Linde and Sacks, 1998; Hill et al., 2002; Manga and Brodsky, 2006; Walter, 2007). The possibility of a triggering of earthquakes by volcanic activity has been proposed by a scant group of people (Critikos, 1946; Kimura, 1976; Acharya, 1982; among others), and the mutual influence of volcanic activity on great earthquakes occurrence and viceversa by Coulomb stress time variations has been investigated by Nostro et al. (1998) on Southern Italian region.

Interaction between volcanoes and earthquakes has been hypothesized carried by at least three physical phenomenons: static stress variations, viscoelastic relaxation, dynamic stress induced by seismic body waves and surface waves. These physics interaction processes are considered as the ”final steps” and the earthquakes and volcanoes are credited to be mutually linked through their action (Nostro et al., 1998; Hill et al., 2002).

The Polar Motion is explained by plate tectonics hypothesizing a subtraction of mass due to the melting of the ice cap in the Northern Hemisphere on the Canadian Shield. This slow deglaciation cannot be extrapolated to more than 1My in the past, while we need to reconnect it to the very ancient True Polar Wander (TPW). TPW is ascribed to advections of mass related to geoidal shape, which pattern we cannot know in the deep past (Steinberger and O'Connel, 1997). The anomaly can be resolved in the expanding Earth schema by assuming an emplacement of mass – extruded from the interior – in the Southern Hemisphere on a migrating Nazca region (Scalera, 2006). In this interpretation the TPW path through geological time – with its stasis at 50 My and subsequent inversion of sense (Besse and Courtillot, 2002) – is naturally linked to the North-to-South migrating position of the region of maximum planetary expansion and unbalanced emplacement of mass in the global paleogeography of the expanding Earth framework (Scalera, 2006). The crossing of the equator at about 50 My causes the observed stasis in the TPW path.

Passing from the older coincidence events to the 2010 one (Fig. 2 and Fig. 3), it is clear the trend – as soon as the data have become more precisely located on the time axis – of an enhanced rate of eruptions before the main seismic event.

The 1868 event – In this case (Fig. 3d) we are out from the lacking of data characterizing the 1835 event, but in 1868 no aeronautics was available to perform surveying of the Andean volcanoes. The news was collected only by visual witness by whether inhabitant of localities nearest the volcanic apparatuses or people passing for a direct inspection. The dates of the eruptions may be was confused with the observation dates, displacing the events many months ahead and possibly one or more years ahead. This could be the case of a small group of eruptions of uncertain date grouped in 1869. The peaks of eruptions after the quake, in Fig. 3d can be an artifact.

The 1906 event – This event (Fig. 3c) is indeed a pair of great earthquakes (Ecuador, January 31, M=8.8, Lat=01.0N, Lat=81.5W; Chile, August 16, M=8.4, Lat=33.0S, Lon=72.0W) that occurred on the same year separated by very long distance (3500 km). In Fig. 3 only the southern district appears to have a peak of eruptions correlated to the earthquakes. This time the maximum is one year after the seismic event but the growing of the eruptions amount starts in the same year of the quake. Then the real distribution on the time axis can be different and considering the reasons explained above in the preceding 1868 case, it may be that some of the real onsets have occurred many months before and also one year before.

The 1960 event – The earthquake occurred (1960, Chile, Lat=38.0S, Lon=72.3W, M=9.5) in the times of more modern scientific instrumentations (seismometry entered in a more advanced status) and surveying facilities (quick transportations, airplanes, helicopters, – But difficulties in landing to directly observe the lava flows or debris was cited by Tazieff still in 1962). This time (Fig. 3b) the maximum eruption rate is in the same year and the growing of the rate starts before the quake occurrence. We can state that a real jump from two to six eruptions has occurred from 1958 to 1959.

The 2010 event – This time (Fig. 3a) all the onset dates of the eruptive events are known thanks to improvements of satellite, aeronautical and land remote digital surveillance methods. The rate of eruptions occurred in the northern and southern volcanic district increased from one-two erup/year to five in 2009 and we expect that an enhanced rate will be revealed until the end of 2010. The northern volcanic district was particularly active in the interval 2007-2009, while – unexpectedly – the central district with its one or two eruptions/year does not contribute to the constitution of the volcano-seismic correlation event. It is then to be considered as well grounded the statement of a precursory behavior of the northern and southern volcanic activity in this case.

The clue of a possible synchronicity – On the same plot in Fig. 4 I have represented both the secular polar motion (from 1846 to 2009; data of PM from IERS web facilities) and the time of occurrence of the volcano-seismic events of correlations. It is possible to see:

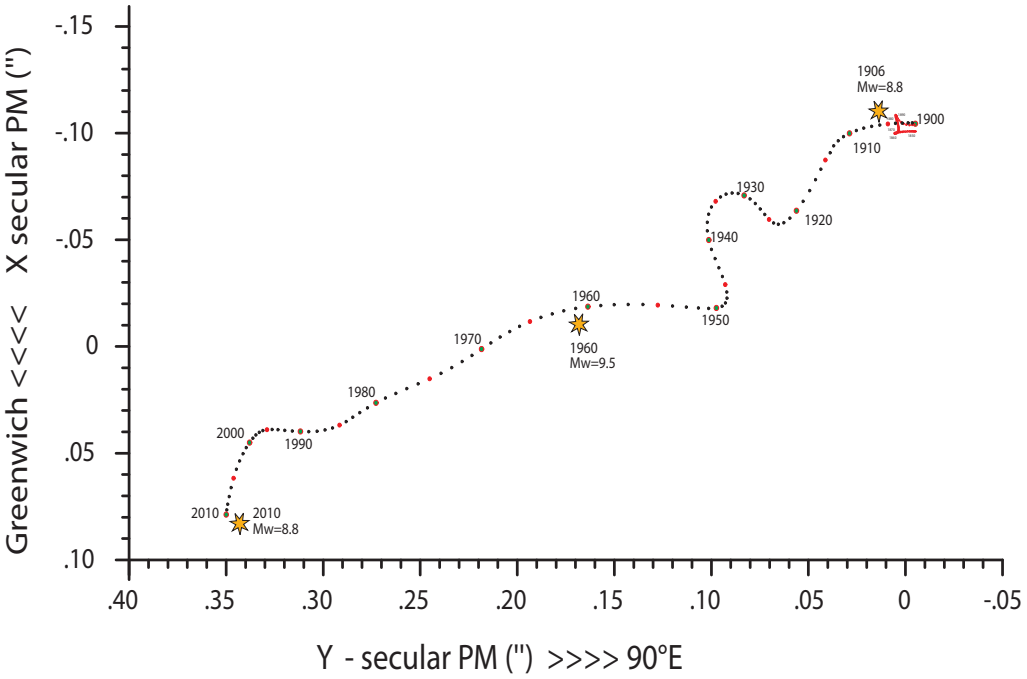

Fig. 3. The secular Polar Motion (PM) from 1846 to 2009. The data 1846-1899 are not omogeneos with the 1900-2009 series and their loop cannot be interpreted. The path is the result of the application of running averages on the PM data. Both the volcano-seismic correlation events of 1960 and the recent one of 2010, occur after ten years from a five-year period of stasis of the secular PM (1945-1950 and 1995-2000). This possible synchronicity must be confirmed or confuted by next centuries of data.

i) – Only three volcano-seismic events can be correlated to the series of PM data 1846-2009, namely the events of 1906, 1960 and 2010 (Fig. 3).

ii) – The PM data preceding 1900 are not homogeneous with the 1900-2009 ones.

iii) – The seismo-volcanic events of 1960 and 2010 occur about 12 years after a five-years window of stasis of the secular PM (a very low velocity, witnessed by the extreme proximity of the annual averaged points in the plot. Albeit the data are not against the same mutual pattern between the event of 1906 and the PM data of the last decade of the XIX century, the non-homogeneity of data do not allow a positive conclusion.

iv) – To ascertain the reality of this further intriguing correlation (or synchronism with the Markowitz oscillation of PM; Poma et al., 1991) a greater amount of volcano-seismic events is needed.

v) – The next expected volcano-seismic correlation will happen within 40-50 years.

Conclusions. The possibility to reveal a number of never suspected integrated phenomena on the side of the maximum asymmetrical expansion of our planet is a further heavy evidence of both the Schiaparelli's envisaged communication between surface and deep geologic realms and a more general evidence in favor of an expanding Earth. However, the planetary expansion schema continues to constitute a formidable challenge to Astronomy and fundamental Physics.

Obviously a part of these arguments (especially the conjecture of synchronicity) claims for a confirmation or confutation by longer time series of data.

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References

Acharya, H. (1982). J. Volcanol. Geotherm. Res., 86, 335-344.

Barrientos, S.E. (1994). PAGEOPH, 142 (1), 225-237.

Besse, J. and Courtillot, V. (2002). J. Geophys. Res., 107 (B11), 2300, doi: 10.1029/2000JB000050.

Carey, S.W. (1976). The Expanding Earth. Elsevier, Amsterdam, 488 pp.

Carr, M.J. (1977). Science, 197, 655-657.

Casertano, L. 1962). Ann. Oss. Vesuviano, 4 (serie 6), 189-216.

Celoria, G. (1910). Rend. Reale Ist. Lomb. Scienze e Lettere, serie II, volume XLIII, 525-532.

Critikos, N.A. (1946). PAGEOPH, 8 (1-2), 145-159.

Darwin, C. (1840). Trans. Geol. Soc. London, 2d ser., pt. 3(5), 601-631.

Gabba, L. (1947). Schiaparelli. La Scuola Editrice, Brescia, 160pp.

Gribaudi, P. (1902) Sulle variazioni della Latitudine. Estratto dalla Rivista di Fisica, Matematica e Scienze Naturali, 66pp.

Hilgenberg, O.C. (1974). Geotektonische Forschungen, 45 (1-2), 159-194.

Hill, D.P., Pollitz, F. and Newhall, C. (2002). Physics Today, November, 41-47.

Kimura, M. (1976). Nature, 260, 131-133.

Larson, R.L. et al. (map's compilers) (1985). The bedrock geology of the world. Freeman and Co.Inc., New York.

Latter, J.H. (1971). Bull. Volcan., 35 (1), 127-142.

Linde, A.T. and I.S. Sacks (1998). Nature, 395, 888-890.

Manga, M. and Brodsky, E. (2006). Annu. Rev. Earth Planet. Sci., 34, 263-291.

McElhinny, M.W. and McFadden, P.L. (2000). Paleomagnetism, continents and oceans. Academic Press, New York, 407pp.

Nostro, C., Stein, R.S., Cocco, M., Belardinelli, M.E. and Marzocchi, W. (1998). J. Geoph. Res., 103 (B10), 24487-24504.

Owen, H.G. (1976). Phil. Trans. R. Soc. London, Series A, 281 (1303), 223-291.

Poma, A., Proverbio, E. and Uras, S. (1991). Il Nuovo Cimento C, 14 (2), 119-125.

Scalera, G. (1999). I moti e la forma della Terra (Motions and shape of the Earth). INGV, Roma, 195pp.

Scalera, G. (2003). In: Scalera, G. and Jacob, K.-H. (eds.): Why expanding Earth? – A book in honour of O.C. Hilgenberg. INGV, Rome, 181-232.

Scalera, G. (2005). Boll. Soc. Geol. It., Special Volume n.5., 129-147.

Scalera, G. (2006). Annals of Geophysics, Supplement to Vol. 49 (1), 483-500.

Scalera, G. (2007a). Rend. Soc. Geol. It., Nuova Serie, 5, 214-218.

Scalera, G. (2007b). NCGT Newsletter, n.43, June, 60-68.

Scalera, G. (2007c). Geofísica Internacional, 46 (1), 19-50.

Scalera, G. (2008). Advances in Geosciences, 14, 41-57.

Scalera, G. (2009). Annals of Geophysics, 52 (6), 615-649.

Scalera, G. (2010a). GeoActa, Spec. Publ. n.3, 'Geology of the Adriatic area', 25-43.

Scalera, G. (2010b). La plate tectonics é una concezione "ticonica"? Giornale di Astronomia, 36 (3), 4-10.

Schiaparelli, G.V. (1891). Il Nuovo Cimento, Terza serie, Tomo XXX, 5-33.

Schiaparelli, G.V. (1883). Boll. del Club Alpino Italiano, 468-486.

Siebert, L., Simkin, T. and P. Kimberly (2011). Volcanoes of the World. Smithsonian Institution/University of California Press, 568pp.

Steinberger, B. and O'Connel, R.J. (1997). Nature, 387, 169-173.

Tazieff, H. (1962). Bull. Volcan., 24 (1), 83-86.

Walter, T.R. (2007). Earth Plan. Sci. Lett., 264, 347-359.